IS 1876 (2005): Voltage Measurement by Means of standard air gap [ETD 19: High Voltage Engineering]

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IS 1876 : 2005
IEC 60052 (2002)
(Reaffirmed 2004)

भारतीय मानक

मानक वायु अंतरालों के माध्यमों से वोल्टेज मापन

(पहला पुनरीक्षण)

Indian Standard

VOLTAGE MEASUREMENT BY MEANS OF STANDARD AIR GAPS

(First Revision)

ICS 19.080

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October 2005 **Price Group 9**

High Voltage Engineering Sectional Committee, ET 19

NATIONAL FOREWORD

This Indian Standard (First Revision) which is identical with IEC 60052 : 2002 'Voltage measurement by means of standard air gaps' issued by the International Electrotechnical Commission (IEC) was adopted by the Bureau of Indian Standards on the recommendations of High Voltage Engineering Sectional Committee (ET 19) and approval of the Electrotechnical Division Council.

The text of the IEC Standard has been approved as suitable for publication as an Indian Standard without deviations. Certain terminology and conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'.

b) Comma (,) has been used as a decimal marker while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

Only the English text of the International Standard has been retained while adopting it as an Indian Standard.

In this adopted standard, reference appears to certain International Standards for which Indian Standards also exist. The corresponding Indian Standards, which are to be substituted in their respective places, are listed below along with their degree of equivalence for the editions indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
IEC 60060-1 (1989) High-voltage test techniques — Part 1 : General definitions and test requirements	IS 2071 (Part 1) : 1993 High-voltage test techniques : Part 1 General definitions and test requirements *(second revision)*	Identical
IEC 60060-2 (1994) High-voltage test techniques — Part 2 : Measuring systems	IS 2071 (Part 2) : 1974 Methods of high voltage testing : Part 2 Test procedure *(first revision)*	Technically equivalent

For the purpose of deciding whether a particular requirement of this standard is complied with the final value observed or calculated, expressing the result of a test or analysis shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

VOLTAGE MEASUREMENT BY MEANS OF STANDARD AIR GAPS

(First Revision)

1 Scope

IEC 60052 sets forth recommendations concerning the construction and use of standard air gaps for the measurement of peak values of the following four types of voltage:

a) alternating voltages of power frequencies;

b) full lightning impulse voltages;

c) switching impulse voltages;

d) direct voltages.

Air gaps constructed and used in accordance with this standard represent IEC standard measuring devices in accordance with IEC 60060-2 and are primarily intended for performance checks of high voltage measuring systems.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60060-1:1989, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60060-2:1994, *High-voltage test techniques – Part 2: Measuring systems*

3 Definitions

vacant

4 Standard sphere-gap

The standard sphere-gap is a peak voltage measuring device constructed and arranged in accordance with this standard. The points on the two spheres which are closest to each other are called the sparking points. Figures 1 and 2 show two arrangements, one of which is typical of sphere-gaps with a vertical axis and the other of sphere-gaps with a horizontal axis.

4.1 Requirements on shape and surface conditions

The standard sphere-gap consists of two metal spheres of the same diameter D, their shanks, operating gear, insulating supports, supporting frame and leads for connection to the point at which the voltage is to be measured. Standard values of D are 2 – 5 – 6,25 – 10 – 12,5 – 15 – 25 – 50 – 75 – 100 –150 and 200 cm. The spacing between the spheres is designated S.

The spheres shall be carefully made so that their surfaces are smooth and their curvature is as uniform as possible.

The tolerances on size and shape need usually only be checked when the spheres are first supplied and any suitable instrument (e.g. spherometer) may be used.

The diameter of each sphere shall not differ by more than 2 % from the nominal value. The spheres shall be reasonably free from surface irregularities in the region of the sparking point. A medium grade mechanical surface finishing (roughness R_{max} below 10 µm) is considered to be adequate. The region of the sparking point is defined by a circle such as would be drawn on the spheres by a pair of dividers set to an opening of 0,3 D and centred in the sparking point.

When the sphere-gap is used, it will normally be sufficient to examine the surface by touch and visual inspection.

NOTE Any minor damage on the non-adjacent hemispherical surfaces does not alter the sphere-gap performance.

4.2 General arrangement of a sphere-gap for measurement

4.2.1 Vertical gap

When the spheres are arranged vertically, the shank of the high-voltage sphere shall be free from sharp edges or corners and the diameter of the shank shall not exceed 0,2 D over a length D. This requirement is made in order to reduce the influence of the high-voltage shank on the disruptive discharge voltage. If a stress distributor (corona shield) is used at the end of the shank, its greatest dimension, perpendicular to the axis of the spheres, shall not exceed 0,5 D and shall be at least 2 D from the sparking point of the high-voltage sphere.

The earthed shank and the operating gear have a smaller effect and their dimensions are therefore less important.

Figure 1 gives the limits of size of the components of a typical vertical sphere-gap.

The sphere shanks should be visually in line.

4.2.2 Horizontal gap

When the spheres are arranged horizontally, the limiting dimensions of a typical sphere-gap are given in figure 2. They are the same for both sides of the gap.

The sphere shanks should be visually in line.

4.2.3 Height of the spheres above the horizontal earth plane

The height A of the sparking point of the high-voltage sphere above the earth plane of the laboratory floor shall be within the limits given in table 1.

If the sphere-gap is mounted with the earthed sphere nearest to the ceiling, and if other surfaces such as walls and the floor are at a considerably greater distance, then the ceiling shall be regarded as the horizontal plane, from which the distance A is measured downwards.

4.2.4 Clearance around the spheres

The distance from the sparking point of the high-voltage sphere to any extraneous objects (such as ceiling, walls, and any energized or earthed equipment), and also to the supporting frame work for the spheres, if this is made of conducting material, shall not be less than the value of distance B in table 1. Except as permitted below, B should not be less than 2 D, regardless of the value of S.

Supporting frameworks for the spheres made of insulating material are exempt from this requirement, provided that they are clean and dry and that the spheres are used for the measurement of alternating or impulse voltages only. The distance B between the sparking point of the high-voltage sphere and the framework may then be less than is prescribed in table 1, however, it shall not be less than 1,6 D.

The peak values of disruptive discharge voltages in tables 2 and 3 are valid for clearances around the spheres within the limits given in table 1.

Table 1 – Clearance limits

Sphere diameter D cm	Minimum value of height A	Maximum value of height A	Minimum value of distance B
Up to 6,25	7 D	9 D	14 S
10 -15	6 D	8 D	12 S
25	5 D	7 D	10 S
50	4 D	6 D	8 S
75	4 D	6 D	8 S
100	3,5 D	5 D	7 S
150	3 D	4 D	6 S
200	3 D	4 D	6 S

The test conditions may make it impossible for the values of A and B to comply with the minimum requirements. Such sphere-gaps can be used, providing that, either the conventional deviation z meets the requirements of clause 5, or, that the uncertainty in the values for disruptive discharge in tables 2 and 3 are suitably increased. Such sphere-gaps could be calibrated under laboratory conditions as indicated in annex D.

The circuit should be arranged so that at the test voltage there is

- no disruptive discharge to other objects,
- no visible leader discharge from the high-voltage lead or the shank within the space defined by B,
- no visible discharge from other earthed objects extending into the space defined by B.

4.3 Connections

The sphere-gap shall be connected in accordance with the requirements specified in IEC 60060-2.

4.3.1 Earthing

One sphere normally shall be connected directly to earth. Low ohmic shunts may be connected between the sphere and earth for special purposes.

4.3.2 High-voltage conductor

The high-voltage conductor, including any series resistor not in the shank itself, shall be connected to a point on the shank at least 2 D away from the sparking point of the high-voltage sphere.

Within the region where the distance to the sparking point of the high-voltage sphere is less than B, the high-voltage conductor (including the series resistor, if any) must not pass through the plane normal to the axis of the sphere-gap and situated at a distance 2 D from the sparking point of the high-voltage sphere. See figures 1 and 2 where the plane is shown.

4.3.3 Protective resistor for measurement of alternating and direct voltages

Precautions should be taken to minimize pitting of the spheres and to prevent superimposed oscillations, which may cause erratic disruptive discharges. For this purpose, a resistance of 0,1 MΩ to 1 MΩ shall be connected in series with the sphere-gap. This range of resistance values applies to measurements of direct voltages and of alternating voltages at power frequencies, because the values of the resistance results in a negligible voltage drop.

The protective resistor should be placed as near as possible to the shank of the sphere and connected directly to it.

When streamer discharges are present in the test circuit, series resistance is particularly important in order to reduce the effect of the consequent transient over-voltage on the operation of the sphere-gap. When these discharges are not present either in the test circuit or in the test specimen, the value of resistance may be reduced to a value which prevents excessive burning of the spheres by disruptive discharges.

4.3.4 Protective series resistor for measurement of impulse voltages

Series resistance is needed with large diameter spheres to eliminate oscillations in the sphere-gap circuit which may cause a higher voltage to occur between the spheres and, if connected, across the test object. This phenomenon is usually of minor importance for smaller spheres, unless they are used with long connecting leads. Series resistance may also be needed to reduce the steepness of the voltage collapse which might introduce undesirable stresses in the test object.

The resistor shall have a non-inductive construction (not more than 30 μH) and its resistance should not exceed 500 Ω. For the position of the resistor in the circuit, see 4.3.2.

5 Use of the sphere-gap

A sphere-gap is an IEC standard measuring device when the conventional deviation z (4.4.5 of IEC 60060-1) at the time of use is less than 1 % for alternating voltages at power frequency and lightning impulse voltages and less than 1,5 % for switching impulse voltages. The conventional deviation z is affected by the condition of the sphere surfaces, the availability of free electrons (sufficient irradiation), the dust contained in the air and the measurement procedures.

5.1 Condition of the sphere surfaces

The surfaces of the spheres in the neighbourhood of the sparking points shall be cleaned and dried but need not be polished. In normal use the surfaces of the spheres become roughened and pitted. The surface should be rubbed with fine abrasive paper and the resulting dust removed with lint-free cloth; any trace of oil or grease should be removed with a solvent. If the spheres become excessively roughened or pitted in use, they shall be repaired or replaced.

Moisture may condense on the surface of the sparking points in conditions of high relative humidity causing measurements to become erratic.

Minor damage to the surface of the sphere beyond the region of sparking point (see 4.1) is not likely to affect the use of the sphere as a measuring device.

NOTE The requirement for the conventional deviation z ensures that the requirements for surface conditions have been met.

5.2 Irradiation

The disruptive discharge voltage of a sphere-gap depends upon the availability of free electrons in the gap between the spheres at the moment of application of voltage. Actions should be taken if the requirements for conventional deviation are not met.

Direct exposure of a sphere-gap to the light from the impulse generator gaps, or to negative polarity corona of the used or separate source, may be sufficient.

Irradiation is usually required for measurements below 50 kV peak for all sphere diameters, and for measurement of voltages with spheres of 12,5 cm diameter and less for all voltage shapes. Methods of arranging irradiation are described in annex C.

NOTE When sufficient irradiation is not available, the uncertainty associated with the values for disruptive discharge in the tables 2 and 3 should be increased.

5.3 Voltage measurements

A measurement of voltage by means of sphere-gap consists of establishing the relation between a voltage in the test circuit, as measured by the standard air gap, and the indication of a voltmeter in the control circuit, or the peak value of the voltage obtained from a suitable measuring or recording device connected to the low voltage side of a measuring system. The spacing between the spheres shall be measured by a method consistent with the overall uncertainty of the voltage measurement. Unless the contrary can be shown, this relation ceases to be valid if the circuit is altered in any respect other than due to a change of the spacing of the spheres.

5.3.1 Measurement of peak value of alternating voltage at power frequency

The voltage shall be applied with an amplitude low enough not to cause disruptive discharge when the supply is energized, and it is then raised sufficiently slowly for the low-voltage indicator to be read accurately at the instant of disruptive discharge of the gap.

A minimum number of 10 successive disruptive discharge voltages shall be recorded in order that the mean value and conventional deviation z can be evaluated. The value of the conventional deviation z shall be less than 1 % of the mean value.

The interval between voltage applications should be not less than 30 s.

5.3.2 Measurement of peak value of full lightning and switching impulse voltages

The 50 % disruptive discharge voltage U_{50} and the conventional deviation z shall be determined. The value of the conventional deviation z shall be not more than 1 % for full lightning impulse voltages and not more than 1,5 % for switching impulse voltages.

This can be done by a multiple level test. A minimum of 10 voltage applications at each of five voltage levels in approximately 1 % steps of the expected disruptive discharge value is needed to obtain U_{50} and to check the conventional deviation z.

It can also be done by an up-and-down-test with a minimum number of 20 voltage applications at approximately 1 % steps of the expected U_{50} voltage.

The criterion for the conventional deviation z shall be checked by applying 15 impulses at a voltage level of U_{50}-1 % for lightning impulse voltages and U_{50}-1,5 % for switching impulse voltages. There shall be not more than two disruptive discharges.

The interval between voltage applications shall be not less than 30 s.

NOTE If, in a particular test, the sphere-gap is used over a gap spacing range, the criterion for the conventional deviation z should be checked for the smallest and largest gap distances.

5.3.3 Measurement of direct voltages

Sphere-gaps are not recommended for the measurement of direct voltages because of the erratic behaviour of these gaps due to fibrous particles in the air which cause erratic disruptive discharges at low voltages. The rod-rod gap is recommended for the measurement of direct voltage in a humidity range from 1 gm^{-3} to 13 gm^{-3}.

When a rod-rod-gap cannot be used, the following procedure for sphere-gaps is recommended. A constant air flow of at least 3m/s should be maintained across the gap. The voltage shall then be applied with an amplitude low enough not to cause disruptive discharge when the supply is energized, and it is then raised sufficiently slowly for the low-voltage indicator to be read accurately at the instant of disruptive discharge of the gap.

The highest stable voltage level at which the breakdown occurs is the value given in table 2.

NOTE The spurious nature of direct voltage breakdown of a sphere-gap might require the tests to be continued for a very large number of voltage applications until a stable upper limit has been established.

6 Reference values in tables 2 and 3

The disruptive discharge voltages for various spacings between spheres are given in tables 2 and 3 for the standard atmospheric conditions for temperature and pressure:

temperature t_0 = 20 °C;

pressure b_0 = 101,3 kPa.

The values in tables 2 and 3 were obtained under conditions of absolute humidity between 5 gm^{-3} and 12 gm^{-3} with an average of 8,5 gm^{-3}.

Table 2 gives the peak value of disruptive discharge voltages (U_{50} values in impulse tests) in kV for:

- alternating voltages at power frequencies;
- full lightning and switching impulse voltages of negative polarity (as defined in IEC 60060-1); and
- direct voltages of both polarities.

Table 3 gives the peak value of disruptive discharge voltages (U_{50} values) in kV for:

- full lightning and switching impulse voltages of positive polarity as defined in IEC 60060-1.

Tables 2 and 3 are not valid for the measurement of impulse voltages below 10 kV.

NOTE Annexes A and B give the range of voltages over which tables 2 and 3 have been derived from experiments, and can be presumed to be within the uncertainty limits given in 6.1.

6.1 Accuracy of values in tables 2 and 3

The values in tables 2 and 3 have been accepted as an international consensus reference standard of measurement.

6.1.1 Alternating and impulse voltages

The values for disruptive discharge voltage given in tables 2 and 3 have an estimated uncertainty of 3 % for a level of confidence not less than 95 %.

Some values are given in tables 2 and 3 for spacings between 0,5 D and 0,75 D. No level of confidence is assigned to those values in brackets.

As it may be difficult to measure and adjust the gap with sufficient accuracy if the ratio of spacing to diameter is very small, it is recommended that the spacing should not be less than 0,05 D.

6.1.2 Direct voltage

There is insufficient information to estimate the uncertainty in measurement values for direct voltages.

6.2 Air density correction factor

Disruptive discharge voltages corresponding to a given spacing under atmospheric conditions other than those specified above are obtained by multiplying the values in tables 2 and 3 by a correction factor corresponding to the relative air density δ.

The relative air density δ is defined by

$$\delta = \frac{b}{b_0} \times \frac{273 + t_0}{273 + t} \tag{1}$$

where

the atmospheric pressures b and b_0 are expressed in the same units (kPa);

t and t_0 are the temperatures in degrees Celsius.

6.3 Humidity correction factor

The disruptive discharge voltage of a sphere-gap increases with absolute humidity at a rate of 0,2 % per gm^{-3}.

The average value of absolute humidity h under which the values in tables 2 and 3 were obtained is 8,5 gm^{-3}. The values in tables 2 and 3 shall be corrected for humidity by multiplying the values in those tables by the humidity correction factor k given by the following equation:

$$k = 1 + (0{,}002 \times (h / \delta - 8{,}5)) \qquad (2)$$

with the ambient absolute humidity h in gm^{-3}.

7 Standard rod-rod gap for measurement of direct voltage

7.1 General arrangement of a rod-rod gap

The general arrangement of a rod-rod gap shall be as shown in either figure 3a (vertical gap) or figure 3b (horizontal gap).

The rods shall be made of steel or brass, with a solid square section, sides between 10 mm and 25 mm and have a common axis. The ends shall be cut at right angles to the axis leaving the edges sharp in order to get a reproducible breakdown mechanism.

The clearance from the tip of the high voltage to earthed objects and walls, other than the ground plane, shall be not less than 5 m.

7.2 Reference values

The disruptive discharge voltage U_0 for positive and negative direct voltage at standard reference atmosphere is given, for either the vertical and horizontal gap by:

$$U_0 = 2 + 0{,}534 \times d \qquad (3)$$

where U_0 is in kilovolts and d is the gap spacing in millimetres.

Equation (3) is valid for gap distances d between 250 mm and 2 500 mm and for a humidity range h/δ between 1 gm^{-3} and 13 gm^{-3}. Under these conditions, the disruptive discharge voltage U_0 has an estimated uncertainty of 3 % for a level of confidence not less than 95 %.

The rod-rod gap shall not be used as an approved measuring device at gap spacing less than 250 mm because of the absence of streamer pre-discharges. There is no experimental evidence to support its use at gap spacings greater than 2 500 mm.

7.3 Measurement procedure

The spacing d between the rods shall be set and the voltage applied and raised so that the time interval between 75 % and 100% of the discharge voltage is about 1 min.

Ten readings of the voltage at the instant of sparkover shall be taken with the voltage indicating device of the measuring system. The voltage, at standard reference atmosphere, corresponding to the mean of these 10 values is given by equation (3). This voltage shall be corrected for the actual atmospheric conditions by taking into account the air density δ (see 6.2) and the humidity correction factor k given by the following equation:

$$k = 1 + (0{,}014 \times (h / \delta - 11)) \qquad (4)$$

for a humidity range h/δ between 1 gm^{-3} and 13 gm^{-3}.

Breakdown voltage values U measured under actual conditions with the temperature t, the pressure b and the absolute humidity h are reported to standard reference atmosphere as follows:

$$U_0 = U / (\delta \times k) \qquad (5)$$

8 Use of standard air gaps for performance checks of approved measuring systems

When a standard air gap is used to make performance checks on a measuring system whose performance is known only insofar as it meets the requirements of an approved measuring system, the two elements of the check circuit will each have an assigned uncertainty of 3 % and therefore differences exceeding this figure could arise in the comparison.

However, when performance checks on the same approved measuring system are repeated, the differences between subsequent measurements, after correction for all atmospheric conditions, can be expected to be appreciably less than 3 %.

Table 2 – Peak values of disruptive discharge voltages (U_{50} values in impulse tests) in kV for alternating voltages at power frequencies, full lightning and switching impulse voltages of negative polarity and direct voltages of both polarities

Sphere-gap spacing cm	Sphere diameter cm											
	2	5	6,25	10	12,5	15	25	50	75	100	150	200
0,05	2,8											
0,10	4,7											
0,15	6,4											
0,20	8,0	8,0										
0,25	9,6	9,6										
0,30	11,2	11,2										
0,40	14,4	14,3	14,2									
0,50	17,4	17,4	17,2	16,8	16,8	16,8						
0,60	20,4	20,4	20,2	19,9	19,9	19,9						
0,70	23,2	23,4	23,2	23,0	23,0	23,0						
0,80	25,8	26,3	26,2	26,0	26,0	26,0						
0,90	28,3	29,2	29,1	28,9	28,9	28,9						
1,0	30,7	32,0	31,9	31,7	31,7	31,7	31,7					
1,2	(35,1)	37,6	37,5	37,4	37,4	37,4	37,4					
1,4	(38,5)	42,9	42,9	42,9	42,9	42,9	42,9					
1,5	(40,0)	45,5	45,5	45,5	45,5	45,5	45,5					
1,6		48,1	48,1	48,1	48,1	48,1	48,1					
1,8		53,0	53,5	53,5	53,5	53,5	53,5					
2,0		57,5	58,5	59,0	59,0	59,0	59,0	59,0	59,0			
2,2		61,5	63,0	64,5	64,5	64,5	64,5	64,5	64,5			
2,4		65,5	67,5	69,5	70,0	70,0	70,0	70,0	70,0			
2,6		(69,0)	72,0	74,5	75,0	75,5	75,5	75,5	75,5			
2,8		(72,5)	76,0	79,5	80,0	80,5	81,0	81,0	81,0			
3,0		(75,5)	79,5	84,0	85,0	85,5	86,0	86,0	86,0	86,0		
3,5		(82,5)	(87,5)	95,0	97,0	98,0	99,0	99,0	99,0	99,0		
4,0		(88,5)	(95,0)	105	108	110	112	112	112	112		
4,5			(101)	115	119	122	125	125	125	125		
5,0			(107)	123	129	133	137	138	138	138	138	
5,5				(131)	138	143	149	151	151	151	151	
6,0				(138)	146	152	161	164	164	164	164	

Table 2 *(continued)*

Sphere-gap spacing cm	Sphere diameter cm											
	2	**5**	**6,25**	**10**	**12,5**	**15**	**25**	**50**	**75**	**100**	**150**	**200**
6,5				(144)	(154)	161	173	177	177	177	177	
7,0				(150)	(161)	169	184	189	190	190	190	
7,5				(155)	(168)	177	195	202	203	203	203	
8,0					(174)	(185)	206	214	215	215	215	
9,0					(185)	(198)	226	239	240	241	241	
10					(195)	(209)	244	263	265	266	266	266
11						(219)	261	286	290	292	292	292
12						(229)	275	309	315	318	318	318
13							(289)	331	339	342	342	342
14							(302)	353	363	366	366	366
15							(314)	373	387	390	390	390
16							(326)	392	410	414	414	414
17							(337)	411	432	438	438	438
18							(347)	429	453	462	462	462
19							(357)	445	473	486	486	486
20							(366)	460	492	510	510	510
22								489	530	555	560	560
24								515	565	595	610	610
26								(540)	600	635	655	660
28								(565)	635	675	700	705
30								(585)	665	710	745	750
32								(605)	695	745	790	795
34								(625)	725	780	835	840
36								(640)	750	815	875	885
38								(655)	(775)	845	915	930
40								(670)	(800)	875	955	975
45									(850)	945	1050	1080
50									(895)	1010	1130	1180
55									(935)	(1060)	1210	1260
60									(970)	(1110)	1280	1340
65										(1160)	1340	1410
70										(1200)	1390	1480
75										(1230)	1440	1540

Table 2 *(continued)*

Sphere-gap spacing cm	Sphere diameter cm										
	2	**5**	**6,25**	**10**	**12,5**	**15**	**25**	**50**	**75**	**100**	**150**	**200**
80											(1490)	1600
85											(I540)	1660
90											(1580)	1720
100											(1660)	1840
110											(1730)	(1940)
120											(1800)	(2020)
130												(2100)
140												(2180)
150												(2250)

NOTE 1 Values are not valid for impulse voltages below 10 kV.

NOTE 2 Figures in brackets, which are for spacings of more than 0,5 D, are of larger uncertainty.

Table 3 – Peak values of disruptive discharge voltages (U_{50} values in impulse tests) in kV for full lightning and switching impulse voltages of positive polarity

Sphere-gap spacing cm	Sphere diameter cm											
	2	5	6,25	10	12,5	15	25	50	75	100	150	200
0,05												
0,10												
0,15												
0,20												
0,25												
0,30	11,2	11,2										
0,40	14,4	14,3	14,2									
0,50	17,4	17,4	17,2	16,8	16,8	16,8						
0,60	20,4	20,4	20,2	19,9	19,9	19,9						
0,70	23,2	23,4	23,2	23,0	23,0	23,0						
0,80	25,8	26,3	26,2	26,0	26,0	26,0						
0,90	28,3	29,2	29,1	28,9	28,9	28,9						
1,0	30,7	32,0	31,9	31,7	31,7	31,7	31,7					
1,2	(35,1)	37,8	37,6	37,4	37,4	37,4	37,4					
1,4	(38,5)	43,3	43,2	42,9	42,9	42,9	42,9					
1,5	(40,0)	46,2	45,9	45,5	45,5	45,5	45,5					
1,6		49,0	48,6	48,1	48,1	48,1	48,1					
1,8		54,5	54,0	53,5	53,5	53,5	53,5					
2,0		59,5	59,0	59,0	59,0	59,0	59,0	59,0	59,0			
2,2		64,0	64,0	64,5	64,5	64,5	64,5	64,5	64,5			
2,4		69,0	69,0	70,0	70,0	70,0	70,0	70,0	70,0			
2,6		(73,0)	73,5	75,5	75,5	75,5	75,5	75,5	75,5			
2,8		(77,0)	78,0	80,5	80,5	80,5	81,0	81,0	81,0			
3,0		(81,0)	82,0	85,5	85,5	85,5	86,0	86,0	86,0	86,0		
3,5		(90,0)	(91,5)	97,5	98,0	98,5	99,0	99,0	99,0	99,0		
4,0		(97,5)	(101)	109	110	111	112	112	112	112		
4,5			(108)	120	122	124	125	125	125	125		
5,0			(115)	130	134	136	138	138	138	138	138	
5,5				(139)	145	147	151	151	151	151	151	
6,0				(148)	155	158	163	164	164	164	164	
6,5				(156)	(164)	168	175	177	177	177	177	

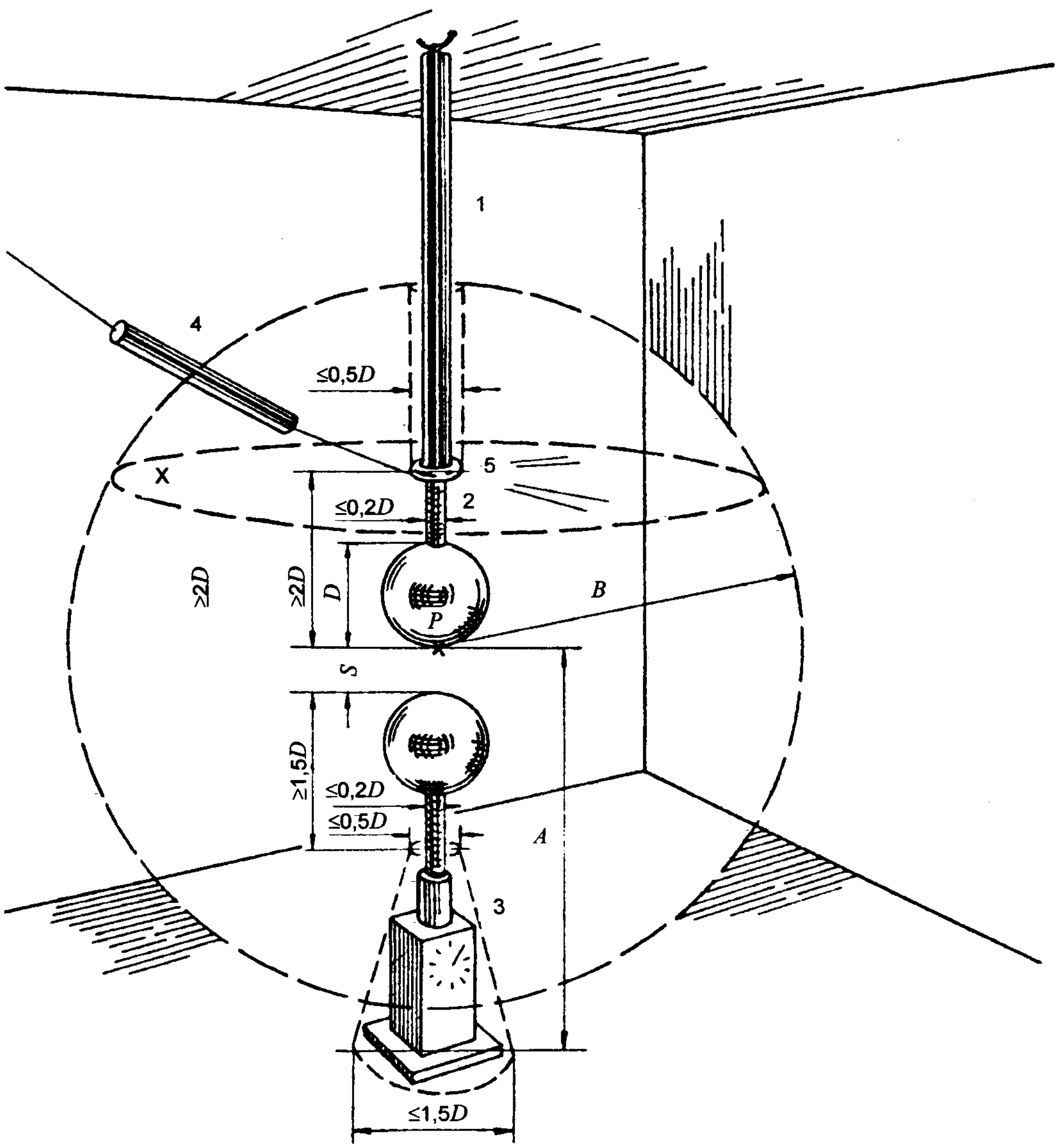
Table 3 *(continued)*

Sphere-gap spacing cm	Sphere diameter cm											
	2	5	6,25	10	12,5	15	25	50	75	100	150	200
7,0				(163)	(173)	178	187	189	190	190	190	
7,5				(170)	(181)	187	199	202	203	203	203	
8,0					(189)	(196)	211	214	215	215	215	
9,0					(203)	(212)	233	239	240	241	241	
10					(215)	(226)	254	263	265	266	266	266
11						(238)	273	287	290	292	292	292
12						(249)	291	311	315	318	318	318
13							(308)	334	339	342	342	342
14							(323)	357	363	366	366	366
15							(337)	380	387	390	390	390
16							(350)	402	411	414	414	414
17							(362)	422	435	438	438	438
18							(374)	442	458	462	462	462
19							(385)	461	482	486	486	486
20							(395)	480	505	510	510	510
22								510	545	555	560	560
24								540	585	600	610	610
26								570	620	645	655	660
28								(595)	660	685	700	705
30								(620)	695	725	745	750
32								(640)	725	760	790	795
34								(660)	755	795	835	840
36								(680)	785	830	880	885
38								(700)	(810)	865	925	935
40								(715)	(835)	900	965	980
45									(890)	980	1060	1090
50									(940)	1040	1150	1190
55									(985)	(1100)	1240	1290
60									(1020)	(1150)	1310	1380
65										(1200)	1380	1470
70										(1240)	1430	1550
75										(1280)	1480	1620

Table 3 *(continued)*

Sphere-gap spacing cm	Sphere diameter cm										
	2	**5**	**6,25**	**10**	**12,5**	**15**	**25**	**50**	**75**	**100**	**150**	**200**
80											(1530)	1690
85											(1580)	1760
90											(1630)	1820
100											(1720)	1930
110											(1790)	(2030)
120											(1860)	(2120)
130												(2200)
140												(2280)
150												(2350)

NOTE The figures in brackets, which are for spacings of more than 0,5 D, are of larger uncertainty.



Key

1 Insulating support

2 Sphere shank

3 Operating gear, showing maximum dimensions

4 High-voltage connection with series resistor

5 Stress distributor, showing maximum dimensions

P Sparking point of high-voltage sphere

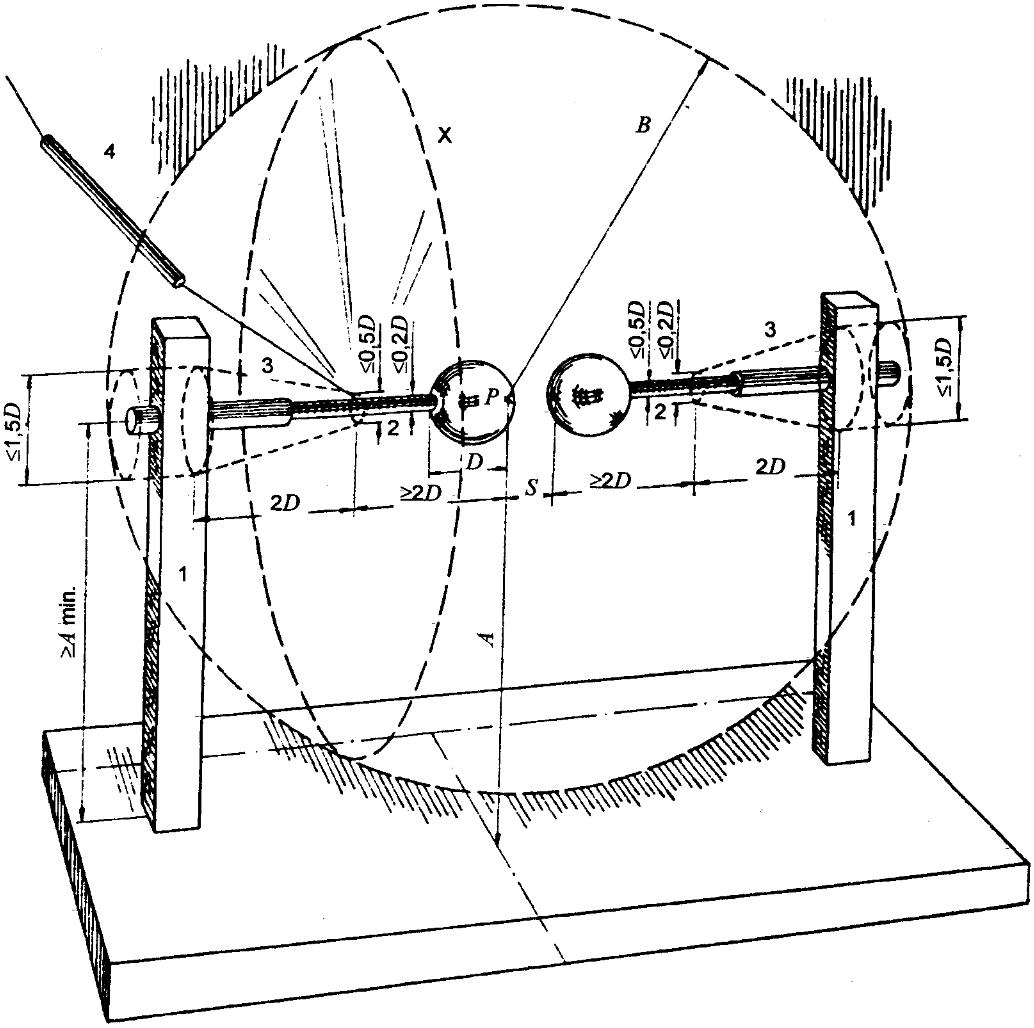
A Height of *P* above earth plane

B Radius of space free from external structures

X Item 4 not to pass through this plane within a distance *B* from *P*

NOTE The figure is drawn to scale for a 100 cm sphere-gap at radius spacing.

Figure 1 – Vertical sphere-gap



Key

1 Insulating support

2 Sphere shank

3 Operating gear, showing maximum dimensions

4 High-voltage connection with series resistor

P Sparking point of high-voltage sphere

A Height of *P* above earth plane

B Radius of space free from external structures

X Item 4 not to pass through this plane within a distance *B* from *P*

NOTE The figure is drawn to scale for a 25 cm sphere-gap at radius spacing.

Figure 2 – Horizontal sphere-gap

Dimensions in millimetres

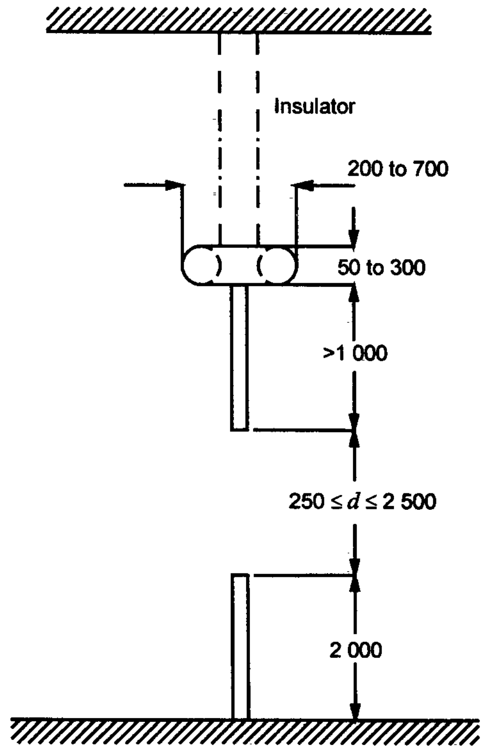


Figure 3a – Vertical arrangement of rod-rod gap

Dimensions in millimetres

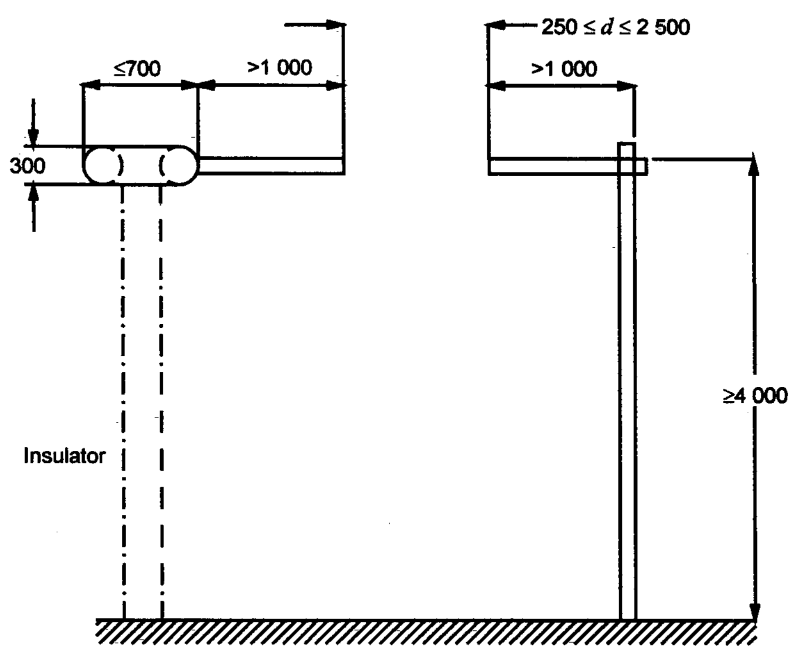


Figure 3b – Horizontal arrangement of rod-rod gap

Figure 3 – Arrangement for rod-rod gap

Annex A
(informative)

Range of experimental calibrations for sphere-gaps

Tables 2 and 3 are partly derived from experiments reported in the references given below. There is no experimental proof of their accuracy at voltages higher than the values given in table A.1.

Table A.1 – Experimental calibrations of the sphere-gap

Kind of voltage	Highest voltage kV peak	Reference
Alternating voltage of power frequency	1700	Transactions AIEE Vol. 71 (1952), Part III, p.455
Alternating voltage of power frequency	1400	JIEE Vol. 82, (1938), p.655
Direct voltage + (sphere-gaps)	800	Zeit. techn. Phys. 18 (1937), p.209
Direct voltage – (sphere-gaps)	1300	Zeit. techn. Phys. 18 (1937), p.209
Impulse voltage + (lightning)	2580	Transactions AIEE Vol. 71(1952) Part III, p.455
Impulse voltage – (lightning)	2410	Transactions AIEE Vol. 71(1952) Part III, p.455
Impulse voltage ± (switching)	1200	ELECTRA No 136, June 1991, p.91-95
Alternating voltage of high frequency		ETZ Vol. 60 (1939), p.92 (see Note 1)
Undamped alternating voltage of high frequency	(See Note 2)	JAIEE Vol. 46 (1927), p.1314 Arch. Elektr. Vol. 14 (1925), p.491 Arch. Elektr. Vol. 24 (1930), p.525 Arch. Elektr. Vol. 25 (1931), p.322 Arch. Elektr. Vol. 26 (1932), p.123
Damped alternating voltage of high frequency	Idem	Ann. Phys. 19 (1906), p.1016 Arch. Elektr. Vol. 16 (1926), p.496 Arch. Elektr. Vol. 20 (1928), p.99

NOTE 1 This reference contains a summary of the calibrations with damped and undamped high-frequency voltages made over a range of voltages and frequencies up to 1939. The other references in the list give the details of most of these individual calibrations.

NOTE 2 From the information in the references, which is incomplete and sometimes conflicting, it appears that table 2 can be used without serious error for the measurement of undamped alternating voltages at frequencies up to 20 kHz but only up to about 15 kV peak. At higher frequencies this voltage is reduced.

The references also show that table 3 can be used for the measurement of damped alternating voltages at frequencies up to 500 kHz, but again with the restriction that the voltage should not exceed 15 kV peak.

Annex B
(informative)

Procedure by which the values in tables 2 and 3 have been derived from national standards and other sources

NOTE The content of this annex is a reproduction of the original "Appendix B" from the former IEC 52: 1960.

At the meeting of Technical Committee No. 42 in Munich in 1956, it was agreed that new tables should be prepared which could be accepted internationally.

Apart from certain exceptions, which are noted below, the disruptive discharge voltages in the new tables were to be the mean of:

a) the values which were accepted by the IEC in Paris in July 1939;

b) the values in A.S.A. standard C 68.1 (1953) (after adjustment for temperature).

The calculation of the mean resulted in a few anomalies; in particular the disruptive discharge voltages of small gaps varied rather irregularly as the sphere diameter was increased.

These anomalies have been removed as far as was possible without introducing other anomalies.

The exceptions mentioned above are listed below:

1) No data are given in the ASA standard for spheres of 2, 5, 10 and 15 cm.

   The IEC figures of 1939 for spheres of 5, 10 and 15 cm have therefore been included in the present tables without any changes other than the minor adjustments referred to above.

2) The figures for 2 cm spheres in the IEC agreement of 1939, which were not applicable to positive impulses, were later found to be inaccurate at spacings up to 1 cm. A new calibration has therefore been inserted, based on JIEE, vol. 95 (1948), Part II, p.309, but the values are not applicable to the measurement of impulses of either polarity below 10 kV. See Proc. IEE, Part II, Vol. 101, (1954), p.438, for evidence on this latter point.

3) The IEC data of 1939 for voltages above 1 400 kV are regarded as being less reliable than the most recently measured values in the USA and these latter have therefore been adopted (see ASA C 68.1, 1953 and Transactions AIEE, vol. 71 (1952), Part III, p.455).

   The figures in tables 2 and 3 have been rounded off as indicated in table B.1:

Table B.1 – Rounding off of values in tables 2 and 3

Value kV	Rounded off kV
Up to 50	to the nearest 0,1
Over 50 and up to 100	to the nearest 0,5
Over 100 and up to 500	to the nearest 1
Over 500 and up to 1 000	to the nearest 5
Over 1 000	to the nearest 10

Annex C
(informative)

Sources of irradiation

For alternating voltage, irradiation may be obtained by corona within the test circuit. However, the presence of corona is very often not desired for other reasons, e.g. partial discharge measurement, and therefore extra irradiation is recommended.

For impulse voltage, direct exposure of a sphere-gap to the light from the impulse generator gaps may be sufficient.

The extra irradiation of the gap can be obtained by a quartz tube mercury-vapour lamp where the lamp spectrum falls in the far ultraviolet (UVC). Mercury-vapour lamps where the lamp spectrum falls in the ultraviolet, UVA or UVB, usually have insufficient irradiation and they are therefore not recommended. The rating of the lamp as well as the actual distance from the gap influence the effect of the irradiation.

The extra irradiation of the gap can also be obtained by pre-discharges from a DC corona source with negative polarity.

Annex D
(informative)

Uncertainty and calibration of sphere-gaps

The value of 3 % for the uncertainty in tables 2 and 3 is the dominant term in the estimation of overall uncertainty in a measurement of voltage by means of sphere-gaps.

This value for uncertainty takes account of many factors including rounding of the results for the tables by as much as 1 %. This introduces an error of up to 0,5 % for voltages above 10 kV and a greater error for voltages less than 10 kV. The uncertainty can be reduced significantly through a procedure of internal calibration of the sphere-gap by a laboratory with a suitable reference measuring system at the time of calibration of the laboratory's approved measuring system.

A calibration of the sphere-gap, over a range of spacings, in terms of the voltage measured with a newly calibrated measuring system can be regarded as an internal calibration of the sphere-gap by the laboratory. The overall uncertainty of calibration should be significantly less than that associated with tables 2 and 3.

From the time of calibration, any future difference in the measured voltage values between the measuring system and the sphere-gap, providing the conditions remain unchanged, should be evaluated for consistency with the reduced uncertainty figures obtained from the calibration procedure in order to indicate possible error in the measuring system.

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